Fabrication and Optical Analysis of the ZnO/Ag Backreflector Structure

Participants

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Outline

1. Motivation

2. Background:
   origin and detection of optical losses in the back-reflector

3. Experimental details:
   multitarget sputtering system for metal/ZnO (w/ X. Deng)

4. Growth of atomically smooth Ag/ZnO:
   effect of intermixing

5. Solar cell simulations of intermixing effect

6. Summary and future work

1. Motivation

Goal 1:
Identify the origins of losses in Ag/ZnO and Al/ZnO back-reflectors and mitigate these losses through metal/ZnO deposition and processing.

Goal 2:
Combine novel optical designs with low-loss back-reflectors to minimize overall reflection losses in the near-infrared

2. Background: Origin of Losses in Back-Reflector

Optical absorption in the ZnO and metal due to their intrinsic properties

Chemical intermixing at the metal/ZnO interface leading to absorption losses

Physical intermixing due to surface roughness at the metal/ZnO interface leading to absorption losses, including plasmon resonances

General back reflector design leading to enhanced reflection

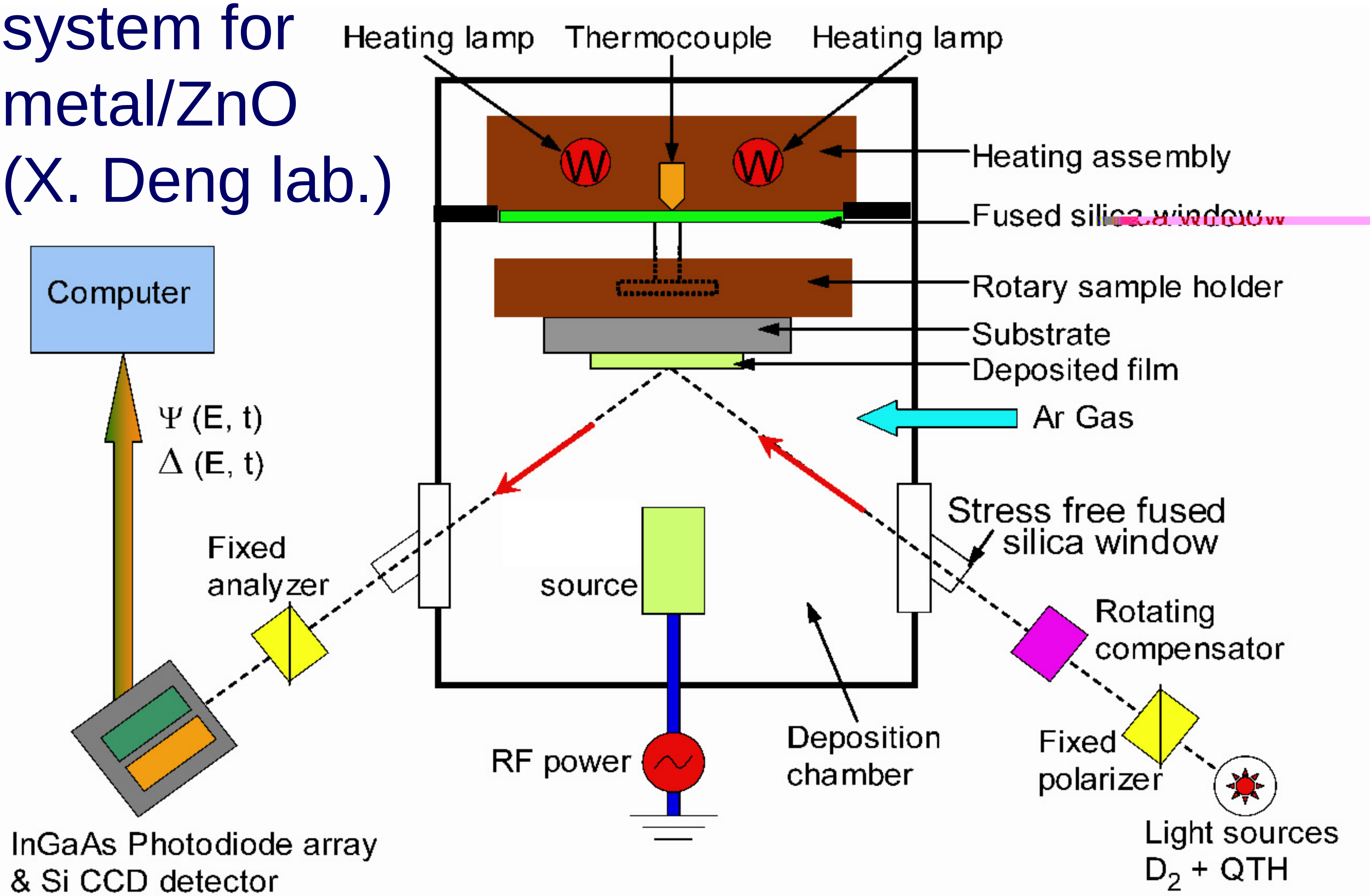
2. Background:
Detection of losses in back-reflector

Approaches

(1) Use a combination of optical probes including RTSE, SE, and T&R to extract the optical properties of the ZnO and metal, removing the extrinsic effects of the surface and interface.
(2) Study the growth of ZnO on atomically smooth metal surfaces by RTSE; characterize the chemical intermixing layer thickness and optical properties.
(3) Study the growth of ZnO on metal surfaces exhibiting different amounts of surface roughness from 10 - 100 Å; separate the rough interface effects from the chemical mixing effects.
(4) Incorporate texture and isolate the macroscopic roughness and non-uniformity from the microscopic-scale structure; in this analysis use the reflectance and the degree of polarization information, and characterize the angular distribution of scattering

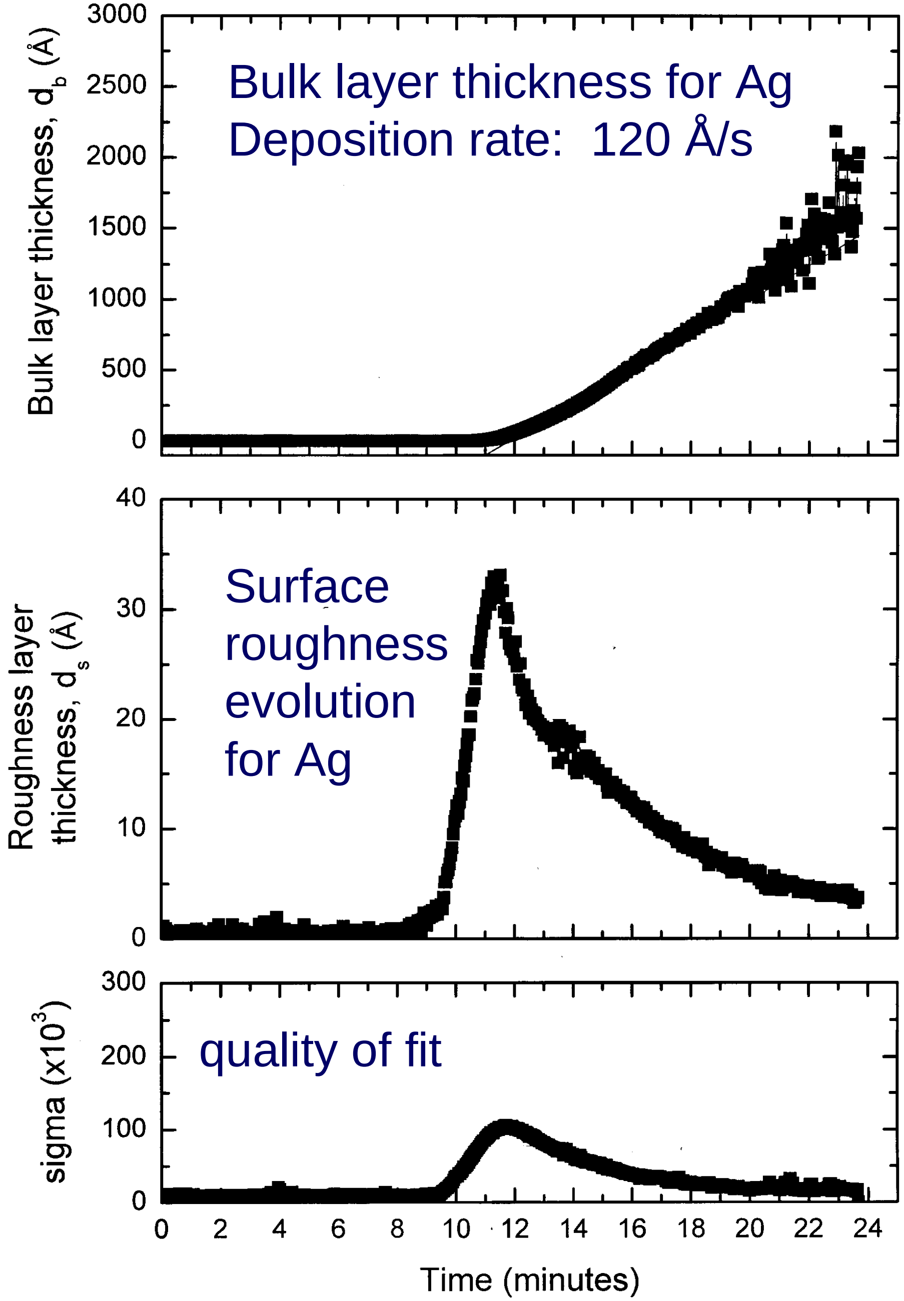
Based on these approaches modify the processes to reduce losses and capture the maximum amount of near-infrared light

3. Experimental details: multi-target sputtering system for metal/ZnO (X. Deng lab.)



Multichannel spectroscopy: 0.75 ~ 6.5 eV; 706 spectral points

Fast spectral acquisition: t_{acq} ~ 32 ms (minimum)



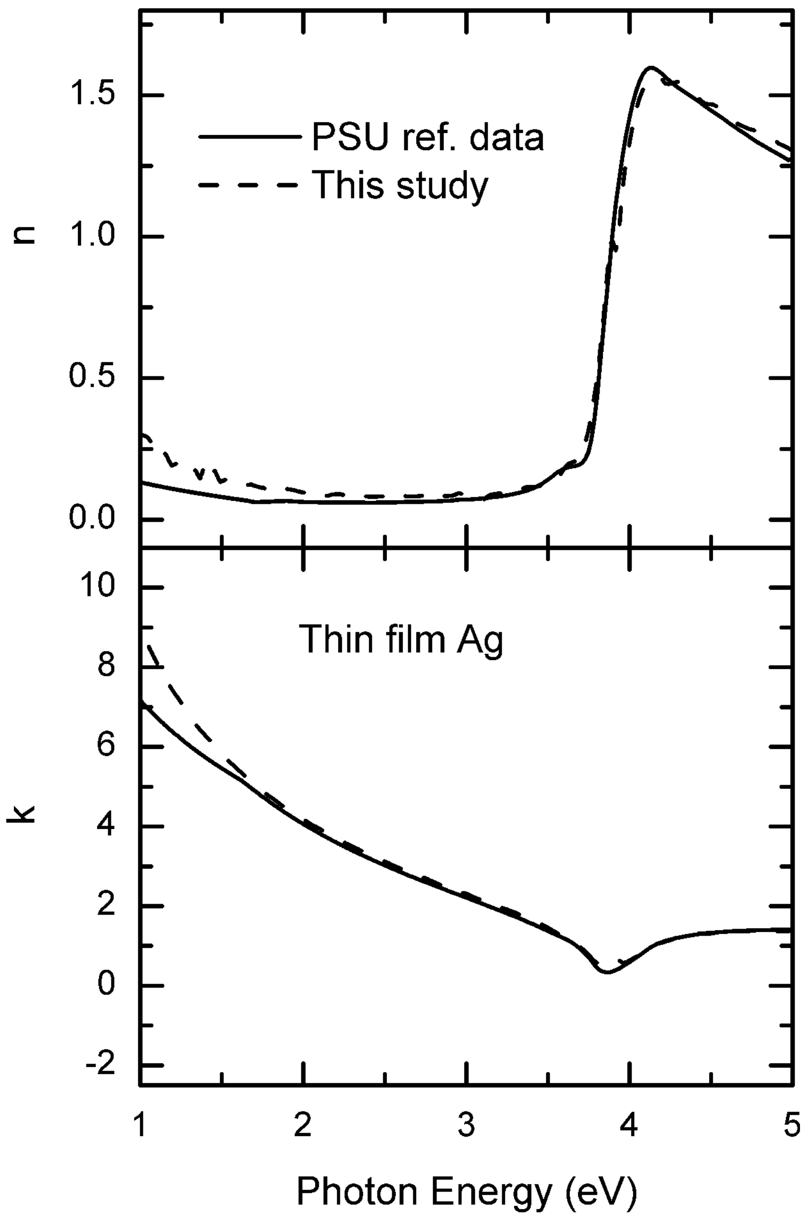
4. Growth of atomically smooth Ag

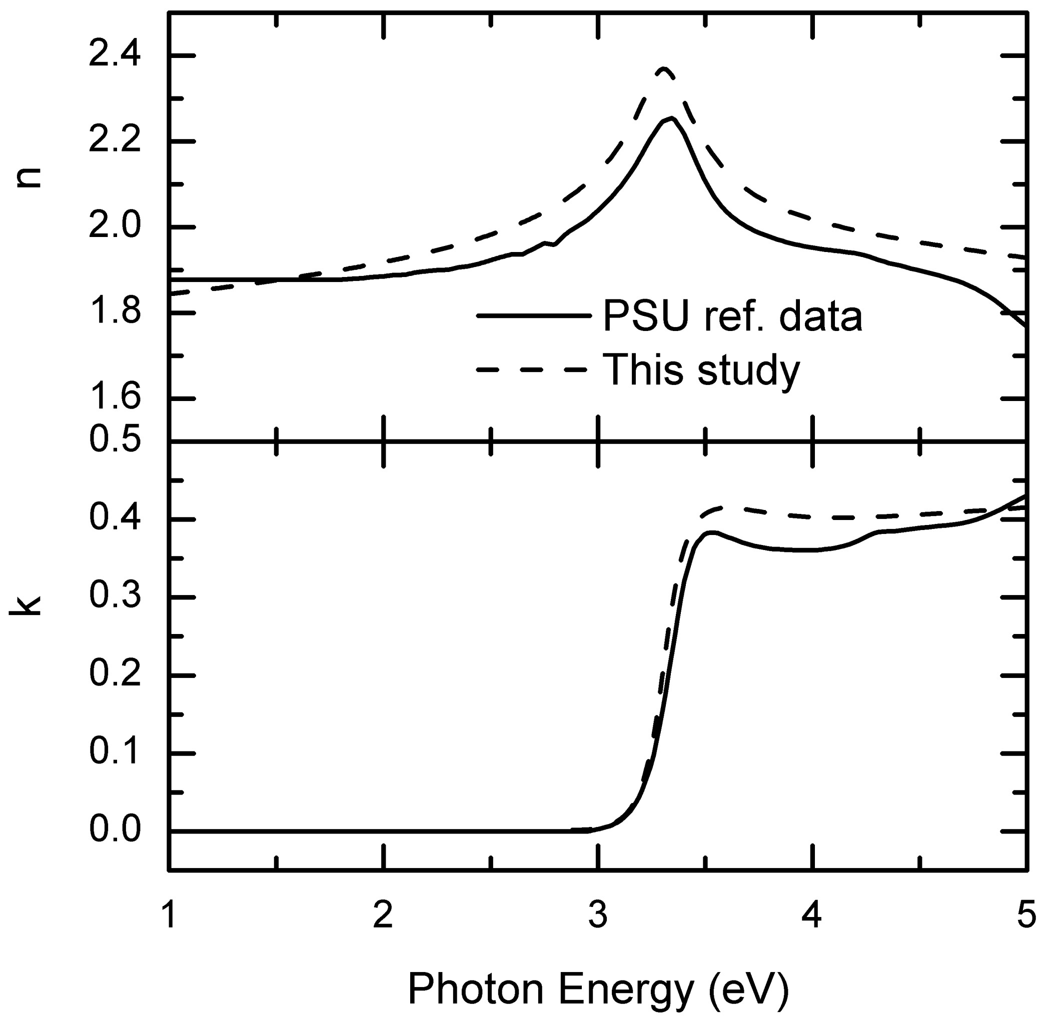
RTSE can be applied to characterize Ag film growth on a c-Si wafer. After a thickness of 1000 A, it becomes difficult to extract the metal thickness

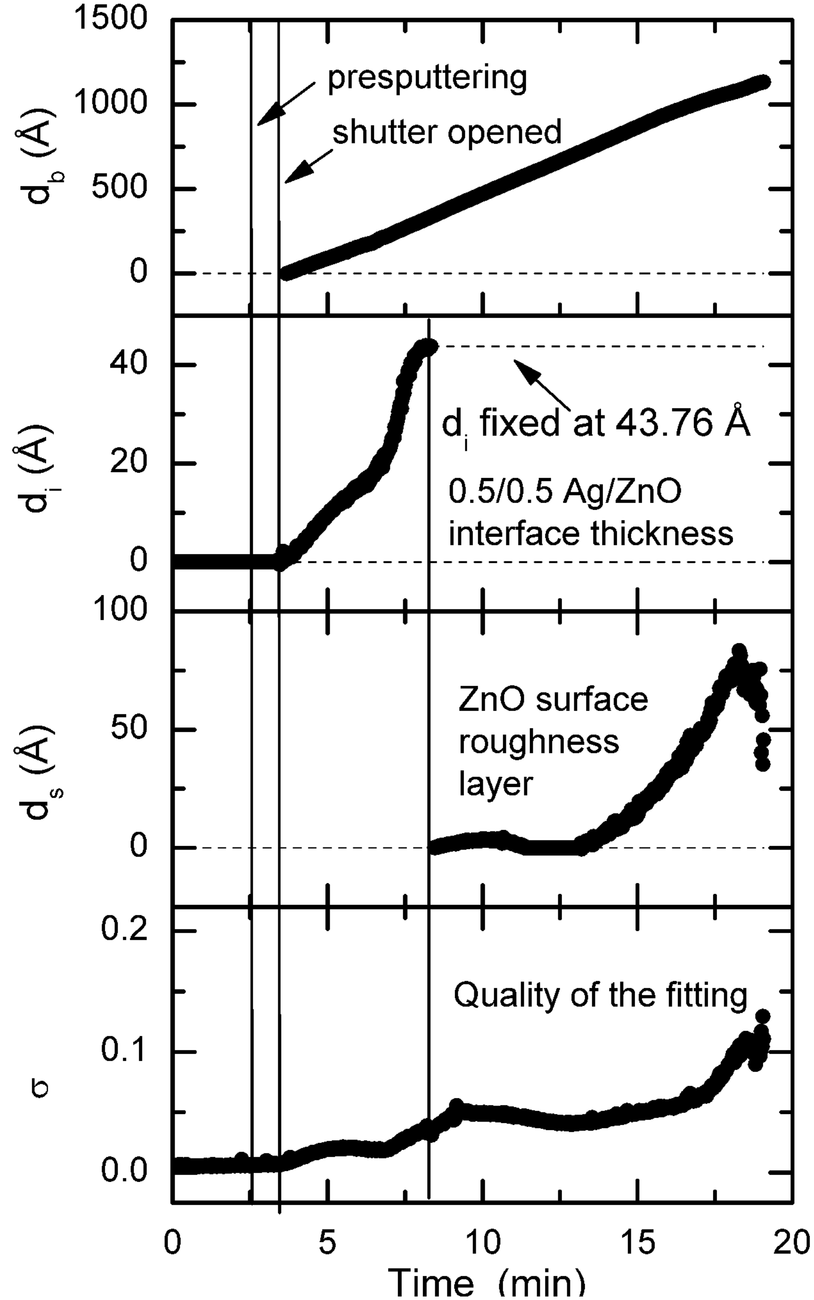
The information of interest is:

- The bulk layer optical properties of the Ag corrected for surface roughness
- The final roughness layer thickness: 4 Å $\Rightarrow$ surface is atomically smooth **This is the desired starting point for studies of intermixing at the interface.**

4. Growth of atomically smooth Ag/ZnO: optical properties

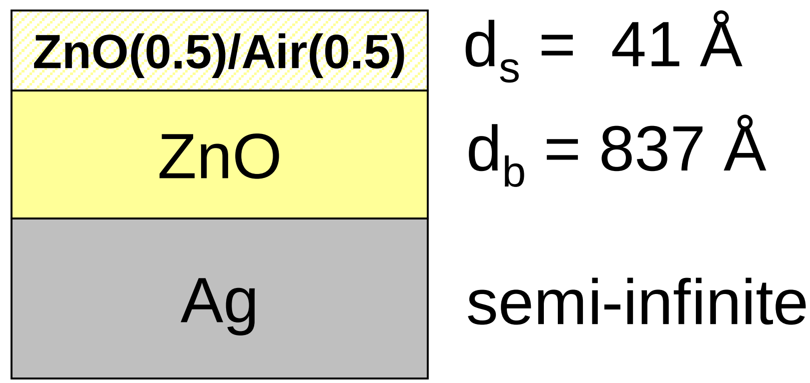




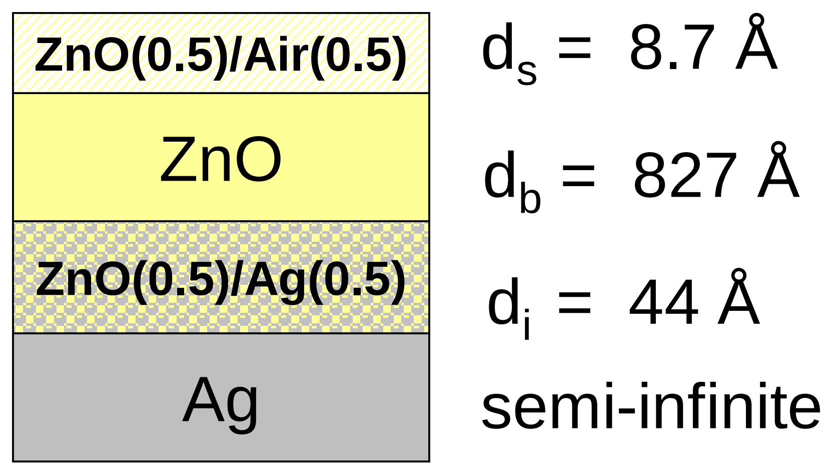


4. Growth of atomically smooth Ag/ZnO: effect of intermixing

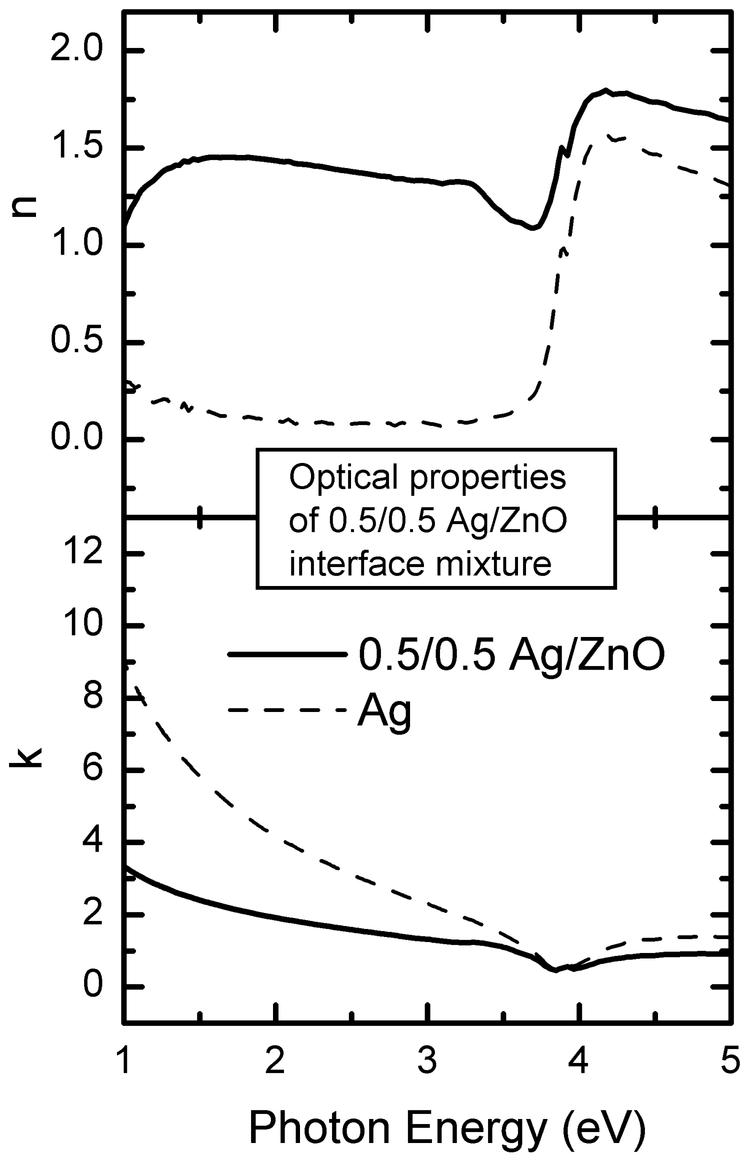
Perfect Interface: t = 14.5 min

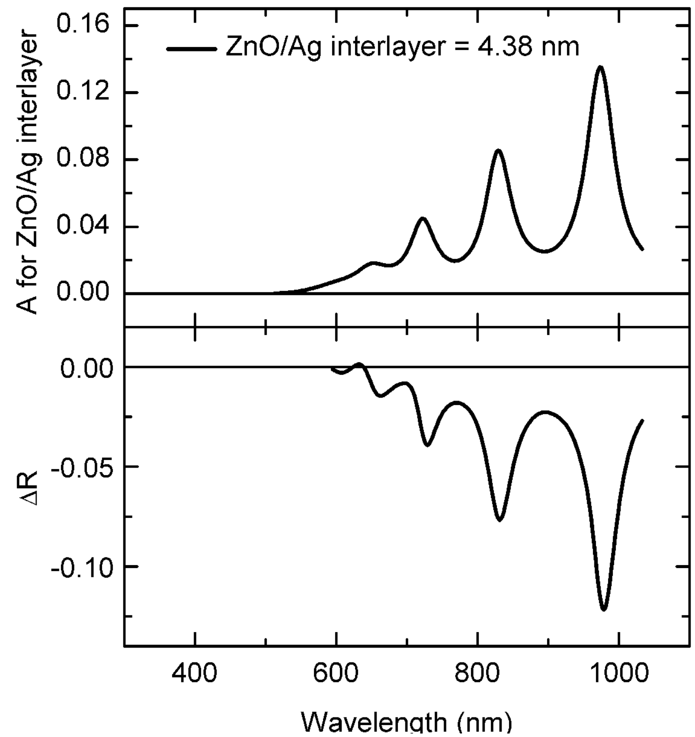


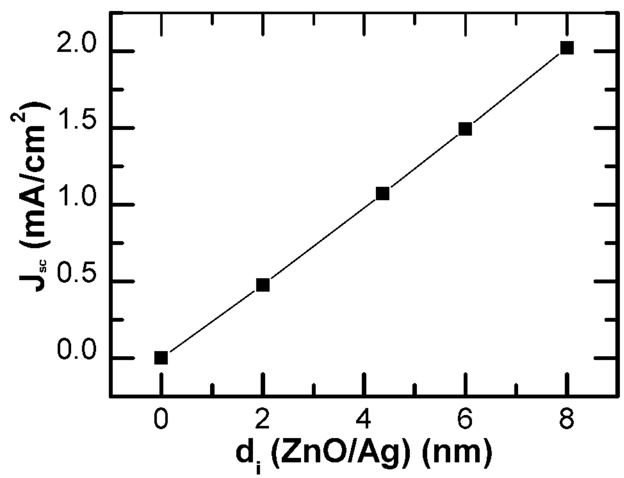
Mixed Interface: t = 14.5 min



5. Solar cell simulations of intermixing effect







Prediction of interface layer effect on single jct. cell output

- Optical properties of interface layer in near infrared metal-like
- Absorption losses exhibit strong interference structure; total ~ 1 mA/cm^2 for interface layer

6. Summary

(1) Using RTSE as a guide, we have deposited Ag with monolayer level smoothness for studies of interfacial chemical mixing, one possible loss mechanism associated with the back-reflector.

(2) The growth of ZnO on atomically smooth Ag surfaces has been studied by RTSE and the interfacial mixing layer thickness and optical properties have been established.

(3) In single junction cell modeling, a total of ~ 1 mA/cm^2 current loss can be associated with absorption losses at the back-reflector interface even when atomically smooth Ag is used.

6. Future

(1) Study the growth of ZnO on metal surfaces exhibiting different amounts of surface roughness: 10 - 100 Å; separate the rough interface effects from the chemical intermixing effects

(2) Incorporate texture and isolate the macroscopic roughness and non-uniformity from the microscopic-scale structure; in this analysis use the reflectance and the degree of polarization information, and characterize the angular distribution of scattering

Based on these approaches modify the processes to reduce losses and capture the maximum amount of near-infrared light